# Southern California Grassland Habitats
## *Climate Change Vulnerability Assessment Synthesis*

***An Important Note About this Document:*** *This document represents an initial evaluation of vulnerability for grassland habitats based on expert input and existing information. Specifically, the information presented below comprises habitat expert vulnerability assessment survey results and comments, peer-review comments and revisions, and relevant references from the literature. The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*


## Executive Summary

Following common vegetation classifications in the literature (e.g., see Jackson and Bartolome 2002; Keeler-Wolf et al. 2007; Spiegal et al. 2014), three grassland groupings occur in the southern California study area: valley/south coastal grassland (including oak savannahs), warm desert grassland (interior), and coastal prairie grasslands (very northern portion of study region). The majority of this assessment focuses on valley/south coastal and coastal prairie grasslands because more information is available for these sub-systems. Grasslands in southern California are typically dominated by high non-native annual cover, but still support a diversity of native annual and perennial species at low abundances (Bartolome et al. 2014; Brandt and Seabloom 2011; Everard et al. 2010; Seabloom et al. 2003a, 2003b; Spiegal at el. 2014). This assessment includes an analysis of both native and non-native annual and perennial grassland components,[1] and where possible, distinctions are drawn between naturalized non-native species[2] and invasive non-native species.[3]

The relative vulnerability of grassland habitats in southern California was evaluated to be moderate[4] by habitat experts due to moderate sensitivity to climate and non-climate stressors, moderate-high exposure to projected future climate changes, and moderate adaptive capacity.

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| **Sensitivity and Exposure** | Climate sensitivities: Precipitation, soil moisture, drought, air temperature<br>Disturbance regimes: Wildfire<br>Non-climate sensitivities: Invasive & problematic species, land-use conversion |

[1] In this assessment, perennial grasslands are defined as having greater than 10% relative perennial cover (Keeler-Wolf et al. 2007).
[2] In this assessment, naturalized non-native species are defined as alien species that now reproduce consistently and sustain populations without, or in spite of, human management (Richardson et al. 2000). Many naturalized non-native annual grasslands provide stable and important ecosystem services (Huenneke and Mooney 1989).
[3] In this assessment, invasive non-native species are defined as plants that produce large numbers of offspring that distribute far from the parent plant, and which typically alter the character, condition, form or nature of large portions of an ecosystem (Richardson et al. 2000).
[4] Confidence: Moderate


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Shifts in moisture availability and timing affect grassland composition, productivity, and species survival. Further, the interplay between temperature, precipitation, and seasonality will likely impact grasslands by affecting the proliferation and abundance of non-native annual grasses. Wildfire and herbivory have variable impacts on grassland communities and vegetation types; for example, both disturbance mechanisms can elevate grassland biodiversity and/or have negative impacts on perennial grasses and other grassland components depending on timing, frequency, intensity, and local site conditions (e.g., soil moisture). Invasive species compete with native species for limited resources, can inhibit native regeneration, and may be able to respond more quickly to climatic variability than native species. Land-use conversion may destroy current habitat, thereby limiting potential refugia and dispersal. In addition, land-use conversion may increase invasive species risk.

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| **Adaptive Capacity** | Habitat extent, integrity, and continuity: Moderate-high geographic extent, low integrity (i.e., degraded), low-moderate continuity<br>Resistance and recovery: Moderate resistance and recovery potential<br>Habitat diversity: Moderate-high overall diversity<br>Management potential: Moderate societal value, low-moderate management potential |

Grassland habitats occupy large portions of the southern California landscape, but their composition has been considerably altered and they are facing significant fragmentation and habitat loss. Although grasslands are generally resilient, perennial species may be less resilient than annual species, leading to a future shift in functional groups. Grasslands have moderate-high diversity, which may enhance their resilience in the face of climate change. Grassland habitats also provide a variety of ecosystem services (e.g., biodiversity, grazing, recreation, carbon sequestration). Potential management options identified by habitat experts largely deal with enhancing native biodiversity and abundance through the use of location-specific grazing, restoration, prescribed burning, and invasive species management practices.

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## Sensitivity

The overall sensitivity of grassland habitats to climate and non-climate stressors was evaluated to be moderate by habitat experts.[5]

**Sensitivity to climate and climate-driven changes**

Habitat experts evaluated grassland habitats to have low-moderate sensitivity to climate and climate-driven changes,[6] including: precipitation, drought, soil moisture, and air temperature.[7]

Precipitation variability

[5] Confidence: High

[6] Confidence: Moderate

[7] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.


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California grasslands experience high inter-annual variability in precipitation (Keeler-Wolf et al. 2007; Potts et al. 2012), and shifts in moisture availability alter grassland productivity (Chou et al. 2008; Dukes et al. 2005; Hamilton et al. 1999; Harpole et al. 2007; Jackson and Bartolome 2002; Potts et al. 2012) as well as species composition and abundance of both native and non-native annual and perennial species from year to year (Bartolome et al. 2014; Chadden et al. 2004; Elmendorf and Harrison 2009; Everard et al. 2010; Jackson and Bartolome 2002; Potts et al. 2012; Seabloom et al. 2003b; Zavaleta et al. 2003). For example, annual grassland productivity increases with rainfall volume (Chou et al. 2008), and consistent rain favors non-native and annual establishment and dominance (Spiegal et al. 2014). El Niño years, which are typically associated with higher precipitation, increase annual forb presence in both warm desert (Keeler-Wolf et al. 2007) and coastal grassland habitats (Seabloom et al. 2003b), and also increase native forb species richness (Z. Principe, pers. comm., 2015).

Shifts in rainfall timing and/or the duration of the growing season may be more important than shifts in total rainfall (Eskelinen and Harrison 2014; Eviner 2014). Shifts in precipitation timing and growing season length affect grassland productivity and species composition (Dukes and Shaw 2007; Kimball et al. 2010; Marty et al. 2005). In addition, longer wet seasons and/or a later start to the wet season affects soil respiration, contributing to carbon loss in annual grasslands (Chou et al. 2008). Growing seasons coincide with periods of highest rainfall (Chadden et al. 2004), extending from late fall through May. Fall and winter precipitation stimulate germination of native annual and perennial grasses and forbs (Bartolome et al. 2014; Keeler-Wolf et al. 2007; Seabloom et al. 2003b), but subsequent rainfall timing and amount affect species composition (Eviner 2014 and citations therein; Marty et al. 2005 and citations therein; Spiegal et al. 2014). For example, periods of low fall or winter precipitation following germinating fall rains favor native forbs, legumes, clovers and perennial grasses over annual grasses (Corbin et al. 2007; Eviner 2014 and citations therein; Keeler-Wolf et al. 2007). Spring rains can have diverse impacts depending on the species that survived prior rainfall and temperature variations; impacts may include increased perennial abundance and productivity (Marty et al. 2005), native forb abundance and diversity, grass diversity, and/or non-native abundance (Eviner et al. in press cited in Eviner 2014). In general, annual grassland species may be more vulnerable than perennial species to shifts in rainfall timing, as precipitation is linked with germination (Bartolome et al. 2014; Kimball et al. 2010). Perennial grasses may be less affected by inter-annual variability in precipitation timing and volume (Brandt and Seabloom 2011) as long as sufficient moisture percolates into deeper soil horizons.

Altered precipitation timing may also facilitate establishment of new exotics (e.g., tropical perennial C4 grasses such as buffelgrass [*Cenchrus ciliaris*]) and/or increase cover of problematic invasives (e.g., fountain grass [*Pennisetum setaceum*]), with implications for wildlife habitat value and grazing quality (L. Criley, pers. comm., 2015). For example, increasing late spring moisture may increase the abundance and productivity of non-native annuals that thrive through late summer, including medusahead (*Elymus caput-medusae*) and barbed goat grass (*Aegilops triuncialis*), which are currently problematic in northern California, and non-native forbs like yellow starthistle (*Centaurea solstitialis*) (Eskelinen and Harrison 2014; Eviner 2014).


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Drought

Native perennial grasses, which feature deeper rooting systems, may be more resilient to short-term drought periods than shallow-rooted non-native annual grasses. For example, in a southern California study site, increasing drought severity was associated with increased abundance of native perennials relative to non-native annual grasses in unburned plots (Potts et al. 2012). In contrast, another study found that drought simulated in a greenhouse was associated with the growth of non-native annual grasses more strongly than with *Stipa pulchra*, a native perennial bunchgrass (Hamilton et al. 1999).

Long-term drought periods negatively affect most grassland components. Drought impacts plant physiology, and has been linked with declines in leaf photosynthesis for both perennial and exotic annual species (Potts et al. 2012). Multi-year droughts have been linked with a decline in native perennial grass cover among remnant native grassland mesas in a southern California watershed (S. DeSimone, pers. comm., 2015), as well as with increased mortality in young *S. pulchra* plants (M. Lulow, unpublished data).

Soil moisture

Soil moisture influences current grassland distribution and plays a key role in grassland seed survival. While well-established native grasses with deeper root systems may be able to tolerate drought better than non-native grasses in a given environment and year, native grass distribution is typically associated with more mesic conditions on the landscape level (i.e., north-facing to neutral aspects, partially shaded areas of grasslands, and greater densities on coastal versus inland regions of California), even for more xeric species such as *S. pulchra* (Gelbard and Harrison 2003; Huffaker and Kennett 1959; Lulow and Young 2011; M. Lulow, unpublished data). For example, at two restoration sites with recently established native grasses, density and cover were greater on north versus south-facing aspects, although *S. pulchra* showed weaker trends compared to other species (Kimball et al. 2015; Lulow et al. 2007).

Relative soil moisture also affects seed survival. For example, a field study in coastal and inland grassland locations near Santa Barbara found that annual grassland seed survival was lower in wetter areas, a trend likely linked with fungal pathogen presence in moist environments (Mordecai 2012). In this study, coastal locations actually had lower soil moisture than inland locations due to differences in soil type (i.e. sandy vs. clay soils; Mordecai 2012). High soil moisture can also facilitate conversion to woody species (e.g., shrub or oak woodlands; DeSimone and Zedler 1999; Dukes and Shaw 2007 and citations therein), although this typically occurs only in annual grasslands that were initially type-converted from shrublands via fire (Z. Principe, pers. comm., 2015).

Air temperature

Warming temperatures likely affect grassland production, phenology, and species composition (Dukes and Shaw 2007 and citations therein; Sampson and McCarty 1930). For example, January minimum temperature was a key driver in grassland composition shifts on the Tejon


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Ranch from 2010-2012, in addition to rodent bioturbation and precipitation in February and October (Spiegal and Bartolome 2012). Low temperatures have been associated with declines in germination of some annual grass species (Reynolds et al. 2001), while warm spring temperatures typically increase annual grass growth rates (Dyer and Rice 1999; Reever Morghan et al. 2007; Talbot et al. 1939). Further, annual grassland senescence timing, as well as perennial grass summer dormancy (Laude 1953), is influenced by temperature rather than precipitation (Cleland et al. 2006; Zavaleta et al. 2003). Studies in central northern California found that native grasses were less responsive to changes in temperature than forbs, and that community responses to temperature were moderated by precipitation and nitrogen deposition (Zavaleta et al. 2003). For example, changes in the relative productivity of annual grasses and forbs in California have been associated with precipitation during warmer periods of the growing season in the fall (October-November) or late spring (March-April; Pitt and Heady 1978; Talbot et al. 1939).

The interplay between temperature, precipitation, and seasonality may be particularly important in understanding differences in grassland community dynamics amongst climatic regions within California, as well as the potential impacts of future climate change on grassland habitats. Due to generally rapid germination and growth rates of annual grasses relative to other species (Reynolds et al. 2001 and citations within), as well as increases in annual grass growth rates with warmer temperatures (Dyer and Rice 1999; Reever Morghan et al. 2007; Talbot et al. 1939), precipitation during warmer times of year favor the growth of annual grasses relative to other species. Lack of precipitation during these warm periods appears to favor other vegetative groups (Corbin et al. 2007; Eviner 2014 and citations therein; Keeler-Wolf et al. 2007), perhaps simply by decreasing the proportion of the year favoring maximum annual grass productivity (M. Lulow, pers. comm., 2015). Seasonal and annual climatic variability will likely continue to play a key role in determining grassland composition and diversity (Bartolome et al. 2014; Reever Morghan et al. 2007).

**Sensitivity to disturbance regimes**
Habitat experts evaluated grassland habitats to have low-moderate sensitivity to disturbance regimes[8], including wildfire.[9] Habitat experts also identified herbivory and disease as important disturbance mechanisms for grassland habitats.[10]

<u>Wildfire</u>
In grassland systems, wildfire stimulates the growth and reproduction of grassland species, and typically elevates biodiversity and spatial heterogeneity (Conservation Biology Institute (CBI) 2004; Marty et al. 2005). Wildfire also prevents the establishment of woody species and/or facilitates type conversion from chaparral or sage scrub to grassland systems (Callaway and Davis 1993). Historical fire return intervals in California grasslands ranged from 5-10 years

[8] Confidence: Moderate
[9] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.
[10] Not all habitat experts agreed on these disturbance regimes.


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(Skinner and Chang 1997 and Swetnam et al. 1998 cited in Dukes and Shaw 2007). Many native perennial grassland species are fire-adapted, and resprout quickly post-fire (Chadden et al. 2004 and citations therein). However, fire can still cause significant mortality of established native perennial bunchgrasses (e.g., *S. pulchra*), although fire impacts are likely moderated by a variety of factors (e.g., burn method, intensity, pre-burn site conditions; Marty et al. 2005).

The timing of fire appears to influence post-fire species composition, including native versus exotic and annual versus perennial assemblages (Keeley 2001; Meyer and Schiffman 1999; Seabloom et al. 2005). For example, summer fires increased the abundance of annual species post-fire relative to perennial species in a study near Santa Barbara (Seabloom et al. 2005). Other studies have shown that early spring fires favor resprouting of native bunchgrasses by killing the seeds of non-native annuals (Keeley 2001), but spring fires may also deplete perennial carbohydrate reserves (Sampson and McCarty 1930) and/or kill seeds of desirable forbs (C. McDonald, pers. comm., 2015). Late spring burning has been found to increase native forb (annual and perennial) and non-native annual forb cover for 1-4 years and 1-6 years post-fire, respectively, while decreasing native perennial and non-native annual grass cover for 1-3 and 1-5 years, respectively. However, fire effects are moderated by inter-annual variability in precipitation, and cover patterns typically return to pre-burn conditions within 1-6 years, with significant reversions after the first year given adequate precipitation, and most changes gone by the fourth year. Periods of low precipitation following fire slow the recovery of grasses, resulting in increased forb presence for a greater number of years (Z. Principe, pers. comm., 2015).

Grassland response post-fire is largely influenced by moisture availability (Chadden et al. 2004; D'Antonio et al. 2002). D'Antonio et al. (2002) found that native forb and perennial grass response to fire was influenced more strongly by climate, and more specifically total precipitation, than it was by fire frequency or seasonality. Similarly, post-fire drought periods reduce *S. pulchra* survival (Larios et al. 2013).

<u>Herbivory</u>

Herbivory is a key disturbance mechanism in grassland habitats, slowing succession rates to coastal sage scrub (Callaway and Davis 1993) and helping to mitigate the high biomass and litter accumulation associated with non-native grass cover (Hayes and Holl 2003a and citations therein; Molinari and D'Antonio 2014), with benefits for both native plant species and wildlife (Bartolome et al. 2014; Stahlheber and D'Antonio 2013). Wildlife and insect herbivory, as well as, more recently, domestic livestock grazing, have all acted as significant drivers in California grassland systems (Bartolome et al. 2014; CBI 2004), contributing to a mosaic of species productivity and diversity (CBI 2004; Hayes and Holl 2003a).

Grazing likely affects various grassland life history groups differently, and species response within these life history groupings can also vary greatly (Bartolome et al. 2004, 2014; Hayes and Holl 2003a; Kimball and Schiffman 2003; Stahlheber and D'Antonio 2013). For example, grazing has been shown to benefit native forbs by suppressing exotic grasses and their habitat impacts (e.g., vertical shading, litter accumulation; Bartolome et al. 2014; Stahlheber and D'Antonio


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2013). A meta-analysis of grazing studies in California's Mediterranean grasslands also found that native grass cover increases in response to grazing, but trends are highly variable (Stahlheber and D'Antonio 2013). In coastal prairie ecosystems, as well as in studies conducted in the Sierra foothills and the Central Valley, grazing increased the species richness and cover of annuals, including native forbs and exotic forbs and grasses (Hayes and Holl 2003a; Love 1944; Murphy et al. 1973; Talbot et al. 1939). For perennial species, grazed sites had greater cover of exotic forbs, while ungrazed sites had higher species richness and cover in native forbs. Species richness in native grass species did not differ between grazed and ungrazed sites (Hayes and Holl 2003a). Studies of *S. pulchra*, specifically, have found neutral (Hatch et al. 1999; Hayes and Holl 2003b; Lulow 2008; Marty et al. 2003 [vegetative data only]), positive (Bartolome et al. 2004 [spring grazing only]; Dyer 2002 [unburned plots]), and negative responses to clipping or grazing (Fehmi and Bartolome 2003; Marty et al. 2003 [reproductive data]).

As with precipitation, the frequency and timing of grazing seem to be important in determining neutral or negative effects (Stahlheber and D'Antonio 2013). Multiple grazing or clipping events within a growing season, or grazing or clipping during peak growth just prior to seed production had a negative influence on several perennial grasses (S. DeSimone, pers. comm., 2015), including *S. pulchra* (Sampson and McCarty 1930 and citations within). Conversely, one or two grazing or clipping events during the late winter or early spring had a neutral effect (Bartolome et al. 2004; Sampson and McCarty 1930).

The broad diversity of grassland responses to grazing underscores the importance of maintaining a diverse spatial and temporal grazing matrix (Hayes and Holl 2003a), conducting localized analyses of herbivory impacts and trends (Bartolome et al. 2014; Callaway and Davis 1993; Jackson and Bartolome 2002; Kimball and Schiffman 2003), and developing species- and site-specific management objectives to achieve various management goals (Bartolome et al. 2007; Jackson and Bartolome 2007; Kimball and Schiffman 2003; Stahlheber and D'Antonio 2013). Overall, the large majority of California grassland studies have occurred north of Santa Barbara, and Jackson and Bartolome (2007) caution against generalizing grassland response to grazing across California climatic regions. The results of these studies reinforce the extent to which climate-related changes will impact overall productivity levels, as well as species composition in California grasslands. In addition, it is important to consider potential shifts in wildlife and livestock herbivory patterns, whether as a result of climate change (e.g., shifts in water supply) or of management decisions, and how such shifts will affect grassland species composition and habitat quality and availability for grassland-associated wildlife species (Bartolome et al. 2014; L. Criley, pers. comm., 2015). In general, more studies are needed to determine how to manage grazing for desired grassland plant community characteristics, especially in southern California, given the potential impacts of climate change.

<u>Disease</u>

Exotic annual grasses may facilitate higher disease incidence amongst native grass species by attracting and supporting large aphid populations, which act as pathogen vectors (Malmstrom et al. 2005). Some diseases (e.g., barley and cereal yellow dwarf viruses) may also make perennial grasslands more susceptible to invasion and dominance by exotic annual species by


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affecting perennial fecundity and survival, thereby undermining their competitive advantage (Borer et al. 2007). In addition, fungal pathogens can alter soil moisture-seed survival interactions; in a Santa Barbara field study, applications of fungicide increased annual seed survival during wet periods (Mordecai 2012).

**Sensitivity and current exposure to non-climate stressors**

Habitat experts evaluated grassland habitats to have moderate-high sensitivity to non-climate stressors[11], with an overall moderate-high exposure to these stressors within the study region.[12] Key non-climate stressors identified by habitat experts for grassland systems include: livestock grazing (overgrazing), invasive and problematic species, and land-use conversion.[13,14] The scientific literature also suggests that air pollution may affect this habitat. Habitat experts evaluated exposure to invasive species and air pollution to be fairly consistent across all grassland systems within the study region, while exposure to other stressors tends to be geographically localized (Vulnerability Assessment Reviewers, pers. comm., 2015).

<u>Livestock grazing (overgrazing)</u>

Livestock grazing can have variable influence on grassland communities depending on timing, duration, and intensity, as well as the characteristics (e.g., soil structure) of the habitat in question (Bartolome et al. 2014; CBI 2004; see herbivory discussion above). Although annual grasslands and non-native annual grasses may be more resilient to grazing pressure (CBI 2004), overgrazing can be detrimental for perennial grasslands, particularly during drought periods (Ceballos et al. 2010). Overgrazing removes apical meristems of perennial bunchgrasses, can limit foliar and root growth (CBI 2004), and can facilitate conversion to annual-dominated systems (Ceballos et al. 2010). Cattle trampling may also compact soil, reducing infiltration and increasing bulk density and runoff (Daniel et al. 2002 cited in Jackson and Bartolome 2007). Multi-year studies in Fresno and Santa Barbara have documented impacts such as these in areas with moderate to intensive grazing (Jackson and Bartolome 2007).

<u>Invasive or other problematic species</u>

The introduction and spread of non-native species, ongoing since the mid-1880s, has critically altered California grasslands (CBI 2004; DiTomaso et al. 2007; Keeler-Wolf et al. 2007). Non-native annuals have displaced native taxa (CBI 2004; DiTomaso et al. 2007), becoming dominant species (Mooney and Hobbs 2000) that generally compete for limited resources (e.g., light, soil moisture, space; Dyer and Rice 1999; Menke 1992; Molinari and D'Antonio 2014). Invasive species also limit native species regeneration and seedling establishment, alter grassland physical structure (Molinari and D'Antonio 2014), and alter fire return intervals (CBI 2004; Dukes and Shaw 2007; Larios et al. 2013). Many annual-dominated grasslands are largely considered naturalized[2] at this stage (Bartolome et al. 2014), but new or expanding exotic invaders threaten the integrity and functioning of both native and naturalized non-native

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[11] Confidence: High

[12] Confidence: High

[13] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

[14] Not all habitat experts agreed on the latter two non-climate stressors.


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grasslands within the study region; further, warmer temperature and potential shifts in precipitation could expose southern California grasslands to entirely new invaders (L. Criley, pers. comm., 2015).

Mediterranean herbaceous species are the most common invaders (Keeley 2001). Common invaders in valley/southern coastal grasslands include the genera *Avena*, *Bromus* (Keeler-Wolf et al. 2007), *Erodium*, *Hirschfeldia*, *Sonchus*, *Centaurea*, and *Lactuca*, as well as *Festuca myuros* and *Brassica nigra* (Vulnerability Assessment Reviewers, pers. comm., 2015). Common invaders in warm desert grasslands include: *Brassica tournefortii*, *Bromus madritensis* ssp. *rubens*, *Salsola tragus*, *Schismus arabicus*, and *Schismus barbatus* (Keeler-Wolf et al. 2007).

Invasive exotics may be better than native species at responding to changes in climate via phenotypic plasticity and/or rapid genetic changes. For example, two invasive grasses (*Avena barbata* and *Bromus madritensis*) were found to flower earlier, in addition to other changes, in response to decreasing precipitation (Nguyen et al. in press). Land-use changes (e.g., development), disturbance (e.g., recreation, grazing), and shifts in climatic conditions may all lead to large changes in exotic plant abundance in the future (CBI 2004; Dukes and Shaw 2007; Keeler-Wolf et al. 2007), affecting competitive interactions with native species, the overall persistence and quality of grassland systems (CBI 2004), and overall grassland response to climate change (Dukes and Shaw 2007).

<u>Land-use conversion</u>

Large portions of native perennial grasslands in California have been lost to agricultural, energy (solar and wind), and urban development, and remaining portions now feature high levels of non-native species as a result of subsequent disturbance (e.g., grazing, mechanical disturbance; CBI 2004). In addition to removing current habitat, development may reduce future potential refugia areas, minimize gene flow and dispersal opportunities by fragmenting the landscape, contribute to invasive species spread (e.g., along transportation corridors) and local air pollution (Vulnerability Assessment Reviewers, pers. comm., 2015), and increase the risk of novel species introduction (Bradley et al. 2012).

<u>Air pollution</u>

Southern California experiences some of the highest levels of nitrogen (N) deposition in the United States (> 45 kg N per hectare per year; Bytnerowicz and Fenn 1996; Padgett et al. 1999), 80% of which occurs as dry deposition during summer (Bytnerowicz and Fenn 1996). Weiss (2006) estimates that 30% of California grasslands are exposed to N deposition rates of 5 kg N per hectare per year.

Nitrogen is a limiting nutrient in southern California grasslands (Harpole et al. 2007), and elevated N deposition is correlated with increased invasion success (N. Molinari, unpublished data) and productivity of non-native grasses (Dukes et al. 2005), and minimal or deleterious effects on native forb and perennial communities (Dukes and Shaw 2007 and citations therein). Native grassland species evolved in relatively nutrient-poor soils, which limits their ability to capitalize on nutrient increases (CBI 2004). Additionally, elevated N deposition in combination


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with drought has been linked with post-fire type conversion from sage scrub to non-native annual grasses (Kimball et al. 2014). Coastal sage scrub conversion is more likely in areas with high N deposition due to greater response of annuals to N fertilization (Cox et al. 2014).

## Future Climate Exposure

Habitat experts evaluated grassland habitats to have moderate-high exposure to projected future climate and climate-driven changes,[15] and key climate variables to consider include: increased air temperature, precipitation changes, and increased drought (Table 1). Habitat experts also identified increased wildfire as an important factor to consider for grassland habitats (Table 1).[16] For a detailed overview of how these factors are projected to change in the future, please see the Southern California Climate Overview (http://ecoadapt.org/programs/adaptation-consultations/socal). Habitat experts identified north-facing slopes, slope bases, shaded areas, valley bottoms with deep soils, coastal areas, runoff accumulation areas (e.g., roadsides, train track edges), and higher elevations as potential moisture refugia, particularly for native perennial grasses; clay soils could serve as refugia for native annuals, particularly if combined with grazing to manage non-native annual grasses (Vulnerability Assessment Reviewers, pers. comm., 2015).

**Table 1.** Anticipated grassland habitat responses to climate and climate-driven changes.

| Climate and climate-driven changes | Anticipated grassland habitat response |
|---|---|
| Precipitation<br>*Variable annual precipitation volume and timing, with wetter winters and drier summers; increased climatic water deficit* | • Altered abundance, productivity, seed survival, species composition, and diversity<br>• Years with above average rainfall may favor annuals over perennials, while drier years may favor perennials<br>• Persistent wet conditions in fall or spring may favor annual grasses<br>• Altered precipitation timing may increase new invasive establishment or expansion, shift annual grassland germination, and/or affect soil respiration |
| Drought<br>*Longer, more severe droughts with drought years twice as likely to occur* | • Multi-year or severe droughts may reduce cover and size of native grasses, especially when combined with overgrazing by livestock, and result in mortality of seedlings and young plants |
| Air temperature<br>*+2.5 to +9°C by 2100* | • Accelerated phenology and altered productivity, abundance, and species composition, particularly with increases in average winter temperatures<br>• Warmer temperatures may enhance non-native annual grass growth rates |
| Wildfire<br>*Increased fire size, frequency, and severity* | • Response will depend on timing and moisture availability post-fire<br>• May facilitate type conversion from chaparral and sage |

[15] Confidence: Moderate
[16] Not all habitat experts agreed on this factor.


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| Climate and climate-driven changes | Anticipated grassland habitat response |
|---|---|
| | scrub to non-native annual grassland |

Precipitation, soil moisture, drought

In general, shifts in wet season duration, onset, and total precipitation could affect the productivity and species composition of both perennial and annual grassland systems (Chou et al. 2008; Dukes and Shaw 2007; Eviner 2014). Drought periods may favor perennial species over annual species in a given place or year (Hamilton et al. 1999; Potts et al. 2012), but increasing drought frequency may negatively affect all grassland components (e.g., increased mortality, reduced cover and productivity; Potts et al. 2012; M. Lulow, unpublished data). Shifts in rainfall delivery (e.g., less frequent, more intense rainfall events) may alter plant biomass and diversity (N. Molinari, pers. comm., 2015).

Air temperature

Temperature increases will likely exacerbate moisture stress and drought risk and severity (Griffin and Anchukaitis 2014). Warmer winter temperatures are also predicted to elevate productivity (particularly of annual grasses) as well as accelerate flowering and senescence of many species (Dukes and Shaw 2007). However, southern California may exhibit less of a response to warming temperatures than northern California, since average temperatures during the winter have historically been warmer (M. Lulow, pers. comm., 2015).

Wildfire

Increasing fire frequency and severity may increase rates of type conversion from chaparral and sage scrub to non-native annual grassland habitat (Callaway and Davis 1993; PRBO Conservation Science 2011), particularly if combined with drought and elevated nitrogen deposition (Kimball et al. 2014). Lenihan et al. (2008) project an increase in grassland area in California by the end of the century, largely at the expense of sage scrub and chaparral habitat. A separate ecoregional study conducted by PRBO Conservation Science (2011) found similar patterns, projecting an increase in grassland area in various regions of California, including southwestern (+345% to +390%) and central western (+85% to +140%) portions of the state. However, it is unknown if and to what extent these type-converted grasslands will support native perennial grassland species (Vulnerability Assessment Reviewers, pers. comm., 2015).

Species distributions

Despite projected increases in overall grassland habitat, species distribution modeling by Principe et al. (2013) indicates that some species currently dominant in grasslands may experience range reductions by 2065, and that perennial species may experience greater reductions than annuals.

*Native perennials*

For the three native perennial grasses modeled (*Distichlis spicata*, *Melica imperfecta*, and *S. pulchra*), 35-40% of current suitable habitat may be lost by 2065, with seasonal temperature variability and available soil water storage primarily driving changes (Principe et al. 2013). Seasonal temperature variability is also projected to be the main driver behind shifts in native


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perennial forb habitat suitability. By 2065, *Ambrosia psilostachya*, *Sisyrinchium bellum*, and *Dichelostemma capitatum* are projected to lose 20%, 40%, and 60% of current suitable habitat, respectively. Remnant suitable perennial habitat areas are projected to be concentrated close to (e.g., within 7-20 miles) and along the coastline (Principe et al. 2013).

*Native annuals*
Comparatively, 75% of the native annual grassland species modeled by Principe et al. (2013) are projected to maintain 75% or more of their current range by 2065; loss of habitat suitability is generally predicted along eastern habitat margins and in lower elevations of western Riverside County, while coastal areas retain suitability. However, three annual species (*Amsinckia menziesii*, *Acmispon strigosus*, and *Cryptantha intermedia*) are projected to lose more than 50% of suitable habitat range over the same time period. Temperature seasonality, available soil water storage, and precipitation of the driest month were key drivers influencing habitat suitability projections for modeled annual grassland species (Principe et al. 2013).

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## Adaptive Capacity

The overall adaptive capacity of grassland habitats was evaluated to be moderate by habitat experts.[17]

**Habitat extent, integrity, continuity, and permeability**
Habitat experts evaluated grassland habitats to have a moderate-high geographic extent (i.e., habitat occurs across state[s]),[18] low integrity (i.e., habitat is degraded),[19] and feature low-moderate continuity (i.e., only some habitat patches are connected).[20] Habitat experts identified land-use conversion and agriculture as barriers to habitat continuity and dispersal for this ecosystem type.[21]

Currently, the valley/south coastal grassland group extends south along the coastline from Santa Barbara, the warm desert grassland exists in interior regions (Keeler-Wolf et al. 2007), and coastal prairie grasslands exist in the northern part of the study region, extending from the Channel Islands northward (Heady et al. 1977). Native grasslands in California have been extensively altered since pre-colonial times in extent, integrity, and species composition (CBI 2004); native perennial grasslands now occur mainly in remnant patches and represent only a small percent of relative vegetation cover, while annual grasslands are more widespread. However, both perennial and naturalized non-native annual grasslands face fragmentation and habitat loss from agricultural, energy, urban, road, and other development (CBI 2004), while geologic features (e.g., arid zones, mountain ranges) interrupt grassland habitat continuity.

[17] Confidence: High
[18] Confidence: High
[19] Confidence: High
[20] Confidence: High
[21] Barriers presented are those ranked most critical by habitat experts. A full list of evaluated barriers can be found at the end of this document.


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Conversion and fragmentation alter the ability of grasslands to support wildlife (L. Criley, pers. comm., 2015).

Private ranches and conservation easements may help preserve grassland habitat area and continuity by maintaining large swaths of contiguous open space (Bartolome et al. 2014). Unconventional agricultural lands (e.g., orchards with natural understory) may also provide grassland refugia or migration opportunities (Vulnerability Assessment Reviewers, pers. comm., 2015).

**Resistance and recovery**

Habitat experts evaluated grassland habitats to have moderate resistance to climate stressors and maladaptive human responses,[22] and moderate recovery potential.[23] Although grasslands are generally very resilient as a habitat, individual species (both plants and wildlife) will likely vary greatly in their response to climate change (Hayes and Holl 2003a; Principe et al. 2013), leading to new and different community composition due to shifts in functional group dominance (Vulnerability Assessment Reviewers, pers. comm., 2015). Additionally, small and sparse populations generally limit the recovery potential for native grassland species.

*Perennial species*

Established native perennial grasses are fairly resistant to precipitation fluctuations and other climatic variation (Eviner 2014), but seedlings are less resistant, and all perennial age groups may be less resistant to human disturbance than annual species. Native perennial grasses rarely have years of high recruitment (Vulnerability Assessment Reviewers, pers. comm., 2015), are difficult to establish in areas dominated by annual species (Eviner 2014), and have not naturally recovered dominance in annual-invaded areas. In addition, native perennial forbs have small seedbanks (Vulnerability Assessment Reviewers, pers. comm., 2015).

*Annual species*

Non-native and native annual seedbanks can persist from decades to centuries, waiting for optimal environmental conditions (whether climate- or disturbance-related) for germination (Bartolome et al. 2014). In addition, native annual forbs remain dormant until periods of low competition, capitalizing on poor-growth periods experienced by perennial grasses (Eviner 2014). These annual seedbank dynamics enhance the ability of annual species to recover after disturbance or in response to climatic variability (Vulnerability Assessment Reviewers, pers. comm., 2015).

**Habitat diversity**

Habitat experts evaluated grassland habitats to have moderate-high physical and topographical diversity,[24] moderate-high component species diversity,[25] and moderate-high functional group

[22] Confidence: Moderate
[23] Confidence: High
[24] Confidence: Moderate
[25] Confidence: High


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diversity.[26] Although significantly altered, grasslands harbor relatively high biological diversity (Bartolome et al. 2014; Carlsen et al. 2000). For example, coastal prairie grasslands may contain the highest plant diversity of North American grasslands, featuring both native perennial species and over 250 forb species, 33% of which are native annual forbs (Stromberg et al. 2002). Grasslands feature shifting species composition depending on the time of year, disturbance, soil characteristics, and local climatic conditions (Bartolome et al. 2014; Keeler-Wolf et al. 2007); in general, however, perennial species comprise only a small percent of cover (Keeler-Wolf et al. 2007). Species composition varies according to local climate, with different species assemblages and dominance in northern and southern portions of the study region, as well as at different elevations and in western and eastern portions of the desert. Although species diversity is high, native perennial grasslands have low functional group diversity (Keeler-Wolf et al. 2007).

While climate affects landscape-scale temporal and spatial distribution and composition of grassland species, soil and topographic variability largely influence both historical and contemporary grassland species distribution and composition at a smaller scale (Bartolome et al. 2014; Spiegal et al. 2014). For example, soil properties define native perennial grass diversity on local sites; historically, mesic areas, areas along water courses, coastal terraces, and less fertile soils (among other habitats) were home to native perennial grasses, and this likely has important restoration implications (Bartolome et al. 2014; Seabloom et al. 2003b). Native perennial species are typically more prevalent in soils that feature large clay components, are nutrient-poor, and have reduced drainage (CBI 2004 and citations therein). Variable soil arrangements also contribute to the patchy spatial distribution and diverse species assemblages of native annual forbs (Bartolome et al. 2014), and native forb diversity tends to be highly localized (Vulnerability Assessment Reviewers, pers. comm., 2015). As long as ideal soil types and microclimates exist, disturbances favor native annual species (Seabloom et al. 2005), as well as yellow starthistle, non-native mustards, and some non-native perennial forbs (L. Criley, pers. comm., 2015). Land use, livestock grazing, and other human management choices will likely play a role in maintaining grassland habitat diversity and extent in the future (Vulnerability Assessment Reviewers, pers. comm., 2015).

A variety of key perennial vegetation associations occur in valley/south coastal grasslands, each related to specific soil characteristics and moisture regimes (**Table 2**; Keeler-Wolf et al. 2007 and citations therein; Lulow and Young 2011). Common perennial species include *Festuca rubra*, *F. idahoensis*, *Deschampsia cespitosa*, and *Danthonia californica* (Hayes and Holl 2003a). Purple needlegrass (*S. pulchra*) is the most common perennial bunchgrass (Keeler-Wolf et al. 2007).

**Table 2.** Common valley/south coastal grassland species associations, locations, and associated soil characteristics (Keeler-Wolf et al. 2007 and citations therein).

| Species | Typical location | Soil characteristics |
|---|---|---|

[26] Confidence: High


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| Species | Typical location | Soil characteristics |
|---|---|---|
| Purple needlegrass (*S. pulchra*) | Throughout study area | Prefers deep, clay loam to clay soils; also exists on serpentine soils and many other soil types |
| *Bromus carinatus* | Coastal foothills, Santa Ana Mountains | Clay loam soils |
| Blue wild rye (*Elymus glaucus*) | Coastal foothills, adjacent to oak woodlands | Sandy loam soils |
| Meadow barley (*Hordeum brachyantherum*) | Adjacent to marshes/seeps | Heavier soils |
| Creeping wild rye (*Leymus triticoides*) | Beneath valley oaks, floodplains, seeps/drainages | Poorly drained soils |
| Seashore saltgrass (*Distichlis spicata*), Alkali sacaton (*Sporobolus airoides*) | Southern and central coast California | Alkaline soils |
| Big squirreltail (*Elymus multisetus*), Torrey's melicgrass (*Melica torreyana*) | Central Coast Range | Clay/serpentine soils |
| Purple three-awn (*Aristida purpurea*) | Southern California | Granitic, sandy soils |

Warm desert grasslands include a mixture of shrub-steppe and native perennial grasses (**Table 3**), and can also include native forbs (Keeler-Wolf et al. 2007).

**Table 3.** Common warm desert grassland species associations and locations (Keeler-Wolf et al. 2007 and citations therein).

| Species | Typical location |
|---|---|
| Big galleta grass (*Hilaria rigida*) | Eastern Mojave Desert |
| Galleta grass (*Hilaria jamesii*) | Northern Mojave Desert |
| Desert needlegrass (*Achnatherum speciosum*) | Widespread; found throughout Mojave Desert and south to Joshua Tree National Park |
| Purple three-awn (*Aristida purpurea*) | Western Sonoran Desert |
| Dune grassland species | Sonoran and Mojave Deserts, often on isolated dunes |
| Saline grassland species | Saline desert playas and near springs |

Common perennial species in coastal prairie grasslands include *Festuca rubra*, *F. idahoensis*, *Deschampsia cespitosa*, and *Danthonia californica* (Hayes and Holl 2003b).

## Management potential


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Habitat experts evaluated grassland habitats to be of moderate societal value.[27] Grasslands are valued for their aesthetics (e.g., open space, wildflower viewing) and for wildlife habitat provisioning. Grasslands provide a variety of ecosystem services, including: biodiversity, grazing, recreation, carbon sequestration, flood and erosion protection, water supply/quality/sediment transport, fire regime controls, public health benefits, and nitrogen retention (Vulnerability Assessment Reviewers, pers. comm., 2015). Even disturbed or stressed grasslands provide ecosystem services; for example, forbs and legumes are critical interim providers of ecosystem services (e.g., forage, erosion control, water infiltration) in grassland areas that are stressed due to harsh environmental conditions (e.g., drought years; Eviner 2014).

Habitat experts identified that there is low-moderate potential for managing or alleviating climate impacts for grassland habitats.[28] High site variability makes management generalizations for grassland systems difficult and requires tailoring of management techniques to meet local goals and needs (Eviner 2014; Mordecai 2012). Habitat experts identified grazing, restoration, prescribed burning, and invasive species management as actions that will be important to consider for facilitating grassland habitat persistence in the face of climate change. Habitat experts agree that maintaining native diversity will likely be a challenge, even if grassland area expands as a result of climate change (Vulnerability Assessment Reviewers, pers. comm., 2015).

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[27] Confidence: Moderate
[28] Confidence: Moderate


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## Grassland Habitats – Overview of Vulnerability Component Evaluations

**Overall Vulnerability Ranking:**[1] **3 Moderate** **Overall Confidence:**[2] **2 Moderate**

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**SENSITIVITY**

| Sensitivity Factor[3] | Sensitivity Evaluation[4] | Confidence[4] |
|---|---|---|
| Sensitivities to Climate & Climate-Driven Factors | **Overall: 2 Low-Moderate** | **Overall: 2 Moderate** |
| • *Precipitation* | • 5 High | • 3 High |
| • *Soil moisture* | • 4 Moderate-High | • 3 High |
| • *Extreme events: drought* | • 4 Moderate-High | • 3 High |
| • *Air temperature* | • 3 Moderate | • 2 Moderate |
| • *Extreme events: high temperature* | • 2 Low-Moderate | • 2 Moderate |
| • Extreme events: low temperature[5] | • 1 Low | • 2 Moderate |
| • Snowpack depth[6] | • 1 Low | • 2 Moderate |
| • Timing of snowmelt & runoff[6] | • 1 Low | • 2 Moderate |
| • Low stream flows[6] | • 1 Low | • 3 High |
| • High lentic/lotic temperature[6] | • 1 Low | • 2 Moderate |
| Disturbance Regimes | **Overall: 2 Low-Moderate** | **Overall: 2 Moderate** |
| • *Wildfire* | • 3 Moderate | • 3 High |
| • Insects[5] | • 2 Low-Moderate | • 1 Low |
| • Disease[5] | • 2 Low-Moderate | • 2 Moderate |
| • Flooding[6] | • 1 Low | • 3 High |
| • Wind[6] | • 1 Low | • 3 High |
| Non-Climate Stressors – Degree Stressor Affects Sensitivity | **Overall: 4 Moderate-High** | **Overall: 3 High** |
| • *Livestock grazing* | • 3 Moderate | • 2 Moderate |
| • Invasive & other problematic species[5] | • 5 High | • 3 High |
| • Land use conversion[5] | • 4 Moderate-High | • 2 Moderate |
| • Pollution & poisons[7] | • 4 Moderate-High | • 2 Moderate |
| • Fire suppression practices[7] | • 3 Moderate | • 3 High |
| • Agriculture & aquaculture[8] | • 5 High | • 3 High |
| • Energy production & mining[8] | • 5 High | • 3 High |
| • Recreation[8] | • 2 Low-Moderate | • 2 Moderate |

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) - Adaptive Capacity.
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.
[3] Factors with expert consensus are *italicized*; all other factors indicate the percentage of experts who identified that factor as important to consider for the habitat.
[4] Scores presented reflect an average of all scores given by habitat experts for a given factor.
[5] Identified by 80% of habitat experts.
[6] Identified by 60% of habitat experts.
[7] Identified by 40% of habitat experts.
[8] Identified by 20% of habitat experts.


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| Sensitivity Factor[3] | Sensitivity Evaluation[4] | Confidence[4] |
|---|---|---|
| Non-Climate Stressors – Current Exposure to Stressor<br>• *Livestock grazing*<br>• Invasive & other problematic species[5]<br>• Land use conversion[5]<br>• Pollution & poisons[7]<br>• Fire suppression practices[7]<br>• Agriculture & aquaculture[8]<br>• Energy production & mining[8]<br>• Recreation[8] | **Overall: 4 Moderate-High**<br>• 3 Moderate<br>• 5 High<br>• 4 Moderate-High<br>• 4 Moderate-High<br>• 4 Moderate-High<br>• 3 Moderate<br>• 4 Moderate-High<br>• 2 Low-Moderate | **Overall: 3 High**<br>• 2 Moderate<br>• 3 High<br>• 2 Moderate<br>• 2 Moderate<br>• 3 High<br>• 3 High<br>• 3 High<br>• 2 Moderate |
| Other Sensitivities: none identified | N/A | N/A |

**Overall Averaged Ranking (Sensitivity):[9] 3 Moderate**

**Overall Averaged Confidence (Sensitivity):[10] 3 High**

**EXPOSURE**

| Exposure Factor[3] | Exposure Evaluation[4] | Confidence[4] |
|---|---|---|
| Future Climate Exposure Factors<br>• *Increased air temperature*<br>• *Changes in precipitation*<br>• *Extreme events: increased drought*<br>• Increased wildfire[5]<br>• Decreased soil moisture[6]<br>• Extreme events: high temperatures[7]<br>• Extreme events: low temperatures[7]<br>• Extreme events: high flows & runoff[8] | **Overall: 4 Moderate-High**<br>• 4 Moderate-High<br>• 4 Moderate-High<br>• 4 Moderate-High<br>• 4 Moderate-High<br>• 5 High<br>• 4 Moderate-High<br>• 2 Low-Moderate<br>• 2 Low-Moderate | **Overall: 2 Moderate**<br>• 3 High<br>• 3 High<br>• 3 High<br>• 3 High<br>• 3 High<br>• 2 Moderate<br>• 1 Low<br>• 1 Low |

**Overall Averaged Ranking (Exposure):[9] 4 Moderate-High**

**Overall Averaged Confidence (Exposure):[10] 2 Moderate**

**ADAPTIVE CAPACITY**

| Adaptive Capacity Factor | Adaptive Capacity Evaluation[4] | Confidence[4] |
|---|---|---|
| Habitat Extent, Integrity & Continuity | **Overall: 2 Low-Moderate** | **Overall: 3 High** |
| • Geographic Extent | • 4 Moderate-High (Occurs across state[s]) | • 3 High |
| • Structural & Functional Integrity | • 1 Low (Degraded) | • 3 High |
| • Habitat Continuity | • 2 Low-Moderate (Only some habitat patches are connected) | • 3 High |

[9] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[10] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.


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| | | |
|---|---|---|
| Landscape Permeability[3]<br>Key barriers:<br>• *Land use conversion*<br>• *Agriculture*<br>• Transportation corridors[5]<br>• Geologic features[6]<br>• Grazing[7]<br>• Energy production & mining[8] | **Overall: 2 Low-Moderate**<br>Impact on landscape permeability:<br>• High<br>• Moderate-High<br>• High<br>• Low-Moderate<br>• Low-Moderate<br>• Moderate-High | **Overall: 3 High**<br><br>• 3 High<br>• 3 High<br>• 3 High<br>• 2 Moderate<br>• 1 Low<br>• 3 High |
| Habitat Resistance & Recovery<br>• Resistance<br>• Recovery | **Overall: 3 Moderate**<br>• 3 Moderate<br>• 3 Moderate | **Overall: 3 High**<br>• 2 Moderate<br>• 3 High |
| Habitat Diversity<br>• Physical/Topographical Diversity<br>• Component Species Diversity<br>• Functional Group Diversity | **Overall: 4 Moderate-High**<br>• 4 Moderate-High<br>• 4 Moderate-High<br>• 4 Moderate-High | **Overall: 3 High**<br>• 2 Moderate<br>• 3 High<br>• 3 High |
| Management Potential<br>• Habitat Value<br>• Likelihood of Managing or Alleviating Climate Impacts | **Overall: 3 Moderate**<br>• 3 Moderate<br>• 2 Low-Moderate | **Overall: 2 Moderate**<br>• 2 Moderate<br>• 2 Moderate |
| Other Adaptive Capacities: none identified | N/A | N/A |

**Overall Averaged Ranking (Adaptive Capacity):[9] 3 Moderate**

**Overall Averaged Confidence (Adaptive Capacity):[10] 3 High**


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